Influence of energy concentration and feed form of the diet on growth performance and digestive traits of brown egg-laying pullets from 1 to 120 days of age

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A B S T R A C T

A total of 1152 one-day-old Hy-Line Brown pullets were used to study the influence of energy content of the diet and feed form on productive performance and digestive tract traits. From 1 to 45 days (d) of age, there were six diets arranged factorially with three Apparent Metabolizable Energy (AMEn) concentrations (low, medium and high) and two feed forms (mash and pellets). From 45 to 120 d all diets were fed in mash form and therefore, the only difference was the energy content. Each of the 6 treatments was replicated 8 times and the experimental unit was formed by 24 pullets housed in 2 adjacent cages. For the entire experiment, body weight (BW) gain and feed to gain ratio improved as the AMEn of the diet increased ($P<0.001$). Pullets fed pellets from 1 to 45 d of age had higher feed intake and BW gain ($P<0.001$) in this period and higher BW gain ($P<0.01$) cumulatively, than pullets fed mash. At 45 d of age, the relative weight (RW; g/kg BW) of all the segments of the gastrointestinal tract (GIT) was lower for pullets fed with the high- than for pullets fed the medium- or low-energy diets. At 120 d of age the RW of the gizzard was higher ($P<0.01$) for pullets fed the low energy diets than for pullets fed the other diets. The relative length (RL; cm/kg BW) of the GIT was not affected by the energy content of the diet. Feeding pellets reduced the RW of the proventriculus

($P<0.05$), the gizzard ($P<0.001$) and the digestive tract ($P<0.001$), and the RL of the small intestine ($P<0.05$) and the ceca ($P<0.001$) at 45 d of age. The effects of feeding pellets on RW of gizzard and proventriculus were still evident at 120 d of age. We concluded that feeding pellets from 1 to 45 d of age improved feed intake and BW of pullets at 120 d of age, and that an increase in the energy content of the diet increased pullet performance at all ages but reduced the RW of the proventriculus and gizzard.

1. Introduction

Two major factors affecting productive performance of laying hens are body weight (BW) and uniformity at the onset of the egg-laying cycle (Akanbi and Goodman, 1982; Bish et al., 1985). Summers and Leeson (1983) reported that BW of pullets at 18 weeks (wk) of age was the most important factor influencing early egg size. Consequently, a main objective for rearing pullets is to obtain flocks with desirable BW and uniformity at a target age (Hy-Line Brown, 2008). Several nutritional strategies have been recommended to improve BW gain and uniformity of pullets, including the increase in the Apparent Metabolizable Energy (AMEn) content of the diet and feeding pellets instead of mash. Under commercial conditions, energy consumption is the main factor influencing BW gain of pullets (Summers et al., 1987). Cherry et al. (1983) reported that chickens fed high energy diets initially increased their average daily feed intake (ADFI) whereas the opposite effect occurred with low energy diets. In fact, Leeson et al. (1993) indicated that pullets fed a diet containing a 12.67 MJ AMEn/kg consumed 6% more energy than pullets fed a diet containing 11.53 MJ AMEn/kg.

The scientific information available on the influence of feed form on performance of pullets is limited. In Single Comb White Leghorn (SCWL) pullets, Deaton et al. (1988) reported that pelleting increased BW gain (BWG) from 12 to 20 wk of age but that ADFI was not affected. Gous and Morris (2001) found that pullets fed crumbles from 1 to 4 wk and then pellets from 5 to 20 wk of age were 6% heavier and consumed 2% less feed than pullets fed mash. Frikha et al. (2009) observed that pullets fed pelleted diets based on maize or wheat from 1 to 45 days (d) of age, had higher ADFI and BWG but similar feed conversion ratio (FCR) than pullets fed mash at both 45 and 120 d of life. In contrast, Leeson and Summers (1984) indicated that crumbling of rearing diets had no effect on BW of pullets at maturity or on subsequent egg production. However, in this report birds fed crumbles consumed more feed from hatching to 10 wk of age.

Feed form influences organ development and nutrient digestibility in broilers (Choi et al., 1986; Kilburn and Edwards, 2001; Mateos et al., 2002). Nir et al. (1995) found that pelleting reduced by 15% the relative length (RL; cm/kg BW) of the jejunum and the ileum, and Nir et al. (1994) and Corchero et al. (2008) observed that feeding crumbles or pellets to broilers reduced gizzard weight with respect to feeding mash. Recently, Frikha et al. (2009) found that gizzard RW was lighter, and the small intestine (SI) shorter, in pullets fed pellets than in pullets fed mash. The authors have not found any report in the literature, conducted with laying pullets, on the effects of energy concentration of the diet on BW uniformity and the development of the different segments of the gastrointestinal tract (GIT). This study aimed to evaluate the influence of energy concentration and feed form of the diet on growth performance and development of the GIT of Hy-Line Brown pullets from 1 to 120 d of age.

2. Materials and methods

2.1. Husbandry and experimental design

All experimental procedures were approved by the animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial Estado, 2005).

A total of 1152 one-day-old Hy-Line Brown pullets with an initial BW of 36.8 ± 2.45 g were obtained from a commercial hatchery (Avigan Terralta, Tarragona, Spain) and used in this experiment. On arrival to the experimental farm, the pullets were placed in a windowless environmentally controlled room with free access to feed and water. Room temperature was maintained at 32 °C during the first 3 d of life and then, the temperature was reduced gradually until reaching 21 °C at 5 wk. The pullets were kept on a 23 h/d light program for the first wk of life and then, light was decreased 2 h/wk until reaching 12 h of light at 7 wk of age. The birds were weighed individually at 1 day of age and stratified by BW into four groups of 288 pullets each. Forty-eight uniform groups of 24 pullets each (6 from each BW group) were formed and 2 adjacent cages (12 pullets each) constituted the experimental unit. Each cage (0.50 m × 0.76 m, Zucami, Pamplona, Spain) was provided with an open trough feeder and two low pressure nipple drinkers. Eight replicates (24 pullets each) were randomly assigned to each of the six experimental feeding programs. All the pullets were debeaked at 12 d of age and were vaccinated against main diseases (infectious bronchitis disease, infectious bursal disease, Newcastle disease, and *Salmonella spp.*) according to accepted commercial practices.

2.2. Feeding program and experimental diets

The feeding program consisted of three feeds that were supplied from 1 to 45 d (starter), 46–85 d (grower) and 86–120 d of age (developer). From 1 to 45 d of age, the main difference among diets was the energy concentration (LOW, MED and HIG) and the form (mash and 2-mm pellets) of the feed. From 45 to 120 d of age all diets were fed as mash, and therefore, the only difference among treatments was the energy concentration of the diets. The AMEn (MJ/kg) content of the MED diets was, 12.05, 11.72 and 11.55 for starter, grower and developer feeds, respectively. Diets of the LOW and HIG feeding programs had 5% less or more AMEn than diets from the MED program for each of the three periods considered. Within each period, all diets had similar nutrient content per MJ of AMEn (Fundación Española Desarrollo Nutrición Animal, 2003) and met or exceeded the nutritional recommendations of the NRC (1994) for pullets. All the diets were based on cereals (maize, wheat and barley) and soya bean meal and sunflower meal were the main protein sources used (Table 1). The cereals used in the

Table 1
Composition of the experimental diets (g/kg, as-fed basis unless otherwise indicated).

Ingredient	1–45 days[a]			46–85 days			86–120 days		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Maize	374.9	317.5	259.8	192.9	146.0	98.7	91.0	54.4	17.8
Wheat	–	150.0	300.0	58.7	270.0	481.5	89.9	310.0	530.0
Barley	300.0	150.0	–	481.5	270.0	58.7	530.0	310.0	89.9
Rice bran	–	–	–	–	–	–	40.0	40.0	40.0
Soya bean meal, 440 g CP[b]/kg	286.8	320.5	354.5	130.1	159.2	187.6	100.1	118.4	137.0
Soya bean oil	–	23.1	46.2	–	18.2	36.4	0.9	17.7	34.5
Sunflower meal, 320 g CP/kg	–	–	–	100	100.0	100.0	100.0	100.0	100.0
Methionine–OH, 880 g/kg	1.9	2.0	2.1	1.4	1.4	1.5	0.4	0.5	0.5
L-lysine–HCl, 780 g/kg	0.6	0.4	0.1	1.7	1.5	1.3	–	–	–
L-threonine, 980 g	1.1	1.1	1.2	–	0.2	0.5	–	0.1	0.2
Sepiolite[c]	–	–	–	–	–	–	14.0	14.0	14.0
Dicalcium phosphate	6.0	7.1	8.3	2.8	3.8	5.0	2.1	3.0	3.9
Calcium carbonate	21.9	21.2	20.3	24.1	22.6	21.3	24.8	24.8	24.7
Sodium chloride	3.2	3.3	3.5	3.2	3.3	3.5	3.2	3.3	3.5
Vitamin and mineral premix[d]	3.6	3.8	4.0	3.6	3.8	4.0	3.6	3.8	4.0

[a] Diets were offered in mash or pellet form according to treatment.

[b] Crude protein.

[c] Complex magnesium silicate clay.

[d] Supplied per kg of diet: vitamin A (*trans*-retinyl acetate), 9000 IU; vitamin D_3 (cholecalciferol), 2600 IU; vitamin E (DL-α-tocopheryl acetate), 16 mg; vitamin B_1, 1.6 mg; vitamin B_2, 6.5 mg; vitamin B_6, 2.2 mg; vitamin B_{12} (cyanocobalamin), 0.015 mg; vitamin K_3, 2.5 mg; choline (choline chloride), 300 mg; nicotinic acid, 30 mg; pantothenic acid (D-calcium pantothenate), 10 mg; folic acid, 0.6 mg; D-biotin, 0.07 mg; manganese (MnO), 70 mg; zinc (ZnO), 60 mg; iron ($FeSO_4 \cdot H_2O$), 40 mg; copper ($CuSO_4 \cdot 5H_2O$), 7 mg; iodine [$Ca(IO_3)_2$], 0.7 mg; selenium (Na_2SeO_3), 0.3 mg; Roxazyme (1600 U endo-1,4-β-glucanase, 3600 U endo-1,3(4)-β-glucanase, and 5200 U endo-1,4-β-xylanase), 200 mg supplied by DSM, S.A., Madrid, Spain; Natuphos 5000 (300 FTU/kg), 60 mg supplied by BASF Española, S.A., Tarragona, Spain.

mash diets were hammer milled (Model CH-9240, Bühler AG, Uzwil, Switzerland) to pass through a 6-mm screen. To prepare the pelleted feeds, an aliquot part of the three mash diets used from 1 to 45 d of age was reground using the same hammer mill provided with a 2-mm screen, steam-conditioned at 72 °C for 60 s, and passed through a pellet press (Model 508-150, Mabrik, Barbera del Valles, Barcelona, Spain) provided with a die ring with a 32-mm thickness and a 2-mm screen.

2.3. *Laboratory analyses*

Representative samples of the diets were ground in a laboratory mill (Model Z-I, Retsch Stuttgart, Germany) provided with a 1-mm screen and analysed for moisture by the oven-drying method (930.01), total ash by a muffle furnace (942.05), nitrogen by combustion (990.03) using a LECO analyser (Model FP-528, LECO, St. Joseph, MI), and Ca and P by spectrophotometry (968.08 and 965.17) as described by AOAC International (2000). Ether extract was determined by Soxhlet analysis (method 4. B) after 3N HCl acid hydrolysis (Boletín Oficial Estado, 1995) and gross energy was determined using an adiabatic bomb calorimeter (Model 356, Parr Instrument Company, Moline, IL). The calculated and determined analyses of the experimental diets are shown in Table 2. In addition, pellet quality of the starter diets (durability, percentage of fines, and length of the pellets) was measured as indicated by Frikha et al. (2009).

2.4. *Productive performance*

Body weight and feed consumption were recorded by replicate at 45, 85 and 120 d of age. Feed wastage was observed to be negligible and was not measured. Mortality was recorded daily. From these data, BWG, ADFI and FCR were determined by period and cumulatively. In addition, all the pullets (12 birds at 45 d of age and 10 birds at 85 d and 120 d of age) of 1 of the 2 cages of each experimental unit were weighed individually at the same control days and BW uniformity was assessed by calculating the percentage of birds that were within ±1.25 SD of the average BW. The 1.25 SD range was selected to fit the commercial management target for BW homogeneity of pullet flocks (80% of birds within ±10% of the average BW of pullets; Hy-Line Brown, 2008).

2.5. *Gastrointestinal tract development*

At 45 d of age, after the productive performance measurements, two birds were randomly selected from each replicate, weighed individually, and euthanized by CO_2 inhalation. The digestive tract (from the beginning of the proventriculus to the cloaca with content) together with the liver and the pancreas was removed aseptically and weighed. Then, the proventriculus and the gizzard were excised, cleaned from digesta, dried with desiccant paper, and weighed. The weight of the digestive tract, including the digesta content, the liver and the pancreas, and that of the empty organs was expressed relative to live BW (RW, g/kg BW). The length of the duodenum, defined as the region from the pyloric junction to the distal-most point of insertion of the duodenal mesentery, jejunum (from the distal-most point of insertion of the duodenal mesentery to the junction with Meckel's diverticulum), ileum (from the junction with Meckel's diverticulum to ileocecal junction), and the total length of the two ceca (from the ostium to the tip of the right and left ceca) was measured on a glass surface using a flexible tape with a precision of 1 mm and expressed relative to live BW (RL, cm/kg BW).

At 120 d of age, two extra pullets from each replicate chosen at random were euthanized. The procedures used and the measures taken were similar to those indicated at 45 d of age. In addition, the pH of the gizzard content was also measured in duplicate at this age using a digital pH meter (Crison Instruments S.A., Barcelona, Spain) fitted with a fine tip glass electrode (Model 507, Crison Instruments S.A., Barcelona, Spain). The average value of the two measurements was used for statistical analysis.

2.6. *Statistical analysis*

The experimental design was completely randomized with six treatments arranged factorially with energy concentration (LOW, MED and HIG) and feed form (mash and 2-mm pellet) as main effects.

Table 2
Composition of the experimental diets (g/kg, as-fed basis unless otherwise indicated).

Item	1–45 days						46–85 days			86–120 days		
	Pellets			Mash			Mash			Mash		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Calculated analysis[a]												
AMEn (MJ/kg)	11.44	12.05	12.66	11.44	12.05	12.66	11.11	11.71	12.32	10.96	11.55	12.13
Crude fibre	39.0	36.9	34.8	39.0	36.9	34.8	58.0	54.8	51.7	58.7	55.1	51.5
Digestible lysine	8.7	9.2	9.7	8.7	9.2	9.7	7.2	7.6	8.0	5.5	5.8	6.1
Digestible methionine	4.3	4.5	4.7	4.3	4.5	4.7	3.7	3.9	4.0	2.7	2.9	3.0
Digestible threonine	6.9	7.3	7.7	6.9	7.3	7.7	4.7	5.0	5.3	4.5	4.7	5.0
Digestible tryptophan	1.9	2.0	2.2	1.9	2.0	2.2	1.6	1.7	1.9	1.5	1.6	1.7
Available phosphorus	3.9	4.2	4.5	3.9	4.2	4.5	3.4	3.7	4.1	3.4	3.6	3.9
Determined analysis[b]												
Gross energy (MJ/kg)	16.26	16.77	17.31	15.94	1 16.72	17.50	16.29	16.48	17.07	15.85	16.60	16.71
Dry matter	888	891	893	883	885	892	899	902	906	904	904	922
Crude protein	206	212	214	203	210	212	167	175	178	166	170	180
Ether extract	40	54	74	41	53	75	32	44	67	38	59	69
Total ash	51	57	59	55	56	57	49	54	58	62	63	68
Calcium	8.9	8.0	8.5	9.3	8.7	8.5	11.0	10.6	10.8	11.8	10.8	11.8
Total phosphorus	6.1	6.3	7.1	6.8	6.6	7.1	5.8	5.7	6.6	6.1	5.8	5.8

[a] According to Fundación Española Desarrollo Nutrición Animal (2003).
[b] Analysed in triplicate samples.

The data on performance, BW uniformity and GIT traits were analysed using the GLM procedure of SAS software (SAS Institute, 1990). When the model was significant, treatment means were separated using the Tukey's test. Differences between treatment means were considered significant at $P<0.05$. Results in tables are represented as means.

3. Results

The determined chemical analyses of the experimental diets were close to expected values (Table 2). Pellet length (average of 4.13 mm), pellet durability index (average of 97.3%) and proportion of fines (3.6%) were similar for all diets, irrespective of energy content (data not shown).

3.1. *Productive performance*

No interaction between energy concentration and feed form of the diet was detected for any trait studied. Therefore, only main effects are presented. Mortality was low (1.75%) and not related to treatment. Most of the mortality (87.5%) occurred during the first wk of life (data not shown). From 1 to 45 of age and cumulatively (1–120 d) ADFI was reduced and BWG was increased ($P<0.001$) when the AMEn of the diet increased (Table 3). Consequently, FCR was improved ($P<0.001$) with increases in the energy content of the diet. From 1 to 45 d of age, pullets fed pellets had higher ADFI and BWG ($P<0.001$) than pullets fed mash and the difference in BWG was maintained at the end of the experiment ($P<0.01$). Body weight uniformity was not affected by dietary treatment (Table 4).

3.2. *Gastrointestinal tract development*

No interactions between AMEn content of the diet and feed form were detected for any of the traits studied. Therefore, only main effects are presented. At 45 d of age, pullets fed the HIG diets had lower RW of the digestive tract ($P<0.001$), gizzard ($P<0.001$) and proventriculus ($P<0.05$) than pullets fed the LOW and MED diets (Table 5). However, the RL of duodenum, jejunum, ileum and ceca was not

Table 3
Influence of metabolizable energy content (AMEn) and feed form (FF) of the diet on BW gain (BWG, g/d), average daily feed intake (ADFI, g/d) and feed conversion ratio (FCR) of pullets.

Treatment	1–45 days			46–85 days			86–120 days			1–120 days		
	BWG	ADFI	FCR	BWG	ADFI	FCR	BWG	ADFI	FCR	BWG	ADFI	FCR
AMEn[a]												
Low	10.5[b]	27.8[a]	2.65[a]	15.9[c]	70.4[a]	4.42[a]	8.8	76.3[a]	8.69[a]	11.8[c]	56.3[a]	4.77[a]
Medium	10.8[a]	27.5[a]	2.54[b]	16.6[b]	68.4[a]	4.13[b]	8.7	73.2[b]	8.41[a]	12.1[b]	54.5[b]	4.51[b]
High	10.9[a]	26.5[b]	2.44[c]	17.1[a]	65.7[b]	3.85[c]	8.9	69.4[c]	7.87[b]	12.3[a]	52.2[c]	4.23[c]
S.E.M.[b]	0.06	0.15	0.017	0.11	0.62	0.027	0.13	0.80	0.105	0.05	0.45	0.028
FF												
Mash	10.6	26.9	2.55	16.5	67.5	4.11	8.8	72.6	8.27	12.0	53.9	4.50
Pellet	10.9	27.7	2.54	16.6	68.8	4.15	8.8	73.3	8.37	12.2	54.8	4.51
S.E.M.[c]	0.05	0.12	0.014	0.09	0.51	0.022	0.11	0.65	0.086	0.04	0.37	0.023
Effect[d]												
AMEn	***	***	***	***	***	***	0.78	***	***	***	***	***
FF	***	***	0.72	0.26	0.09	0.26	0.91	0.49	0.47	**	0.09	0.71

(a–c) Mean values within a column and main effects not sharing a common superscript are different ($P<0.05$).

** $P<0.01$.

*** $P<0.001$.

[a] AMEn was 11.44, 12.05 and 12.66 MJ/kg from 1 to 45 d, 11.11, 11.71 and 12.32 MJ/kg from 46 to 85 d and 10.96, 11.55 and 12.13 MJ/kg from 86 to 120 d of age for the low, medium and high energy diets, respectively.

[b] Standard error of the mean (16 replicates of 24 pullets from 1 to 45 d of age and 22 pullets from 46 to 120 d of age).

[c] Standard error of the mean (24 replicates of 24 pullets from 1 to 45 d of age and 22 pullets from 46 to 120 d of age).

[d] The interaction between AMEn concentration and feed form was not significant ($P>0.05$).

Table 4
Influence of metabolizable energy content (AMEn) and feed form (FF) of the diet on BW uniformity of pullets at 45, 85 and 120 days of age[a].

Treatment	45 days	85 days	120 days
AMEn[b]			
Low	0.828	0.788	0.800
Medium	0.792	0.763	0.781
High	0.797	0.763	0.794
S.E.M.[c]	0.0314	0.0405	0.0370
FF			
Mash	0.813	0.746	0.775
Pellet	0.799	0.796	0.808
S.E.M.[d]	0.0257	0.0331	0.0302
Effect[e]			
AMEn	0.68	0.88	0.94
FF	0.70	0.29	0.44

[a] Proportion of pullets with a BW within the average ±1.25 SD range.

[b] AMEn was 11.44, 12.05 and 12.66 MJ/kg from 1 to 45 d, 11.11, 11.71 and 12.32 MJ/kg from 46 to 85 d, and 10.96, 11.55 and 12.13 MJ/kg from 86 to 120 d of age for the low, medium and high energy diets, respectively.

[c] Standard error of the mean (16 replicates of 12 pullets from 1 to 45 d of age and 10 pullets from 46 to 120 d of age).

[d] Standard error of the mean (24 replicates of 12 pullets from 1 to 45 d of age and 10 pullets from 46 to 120 d of age).

[e] The interaction between AMEn concentration and feed form was not significant ($P>0.05$).

Table 5
Influence of metabolizable energy content (AMEn) and feed form (FF) of the diet on relative weight (g/kg BW) and length (cm/kg BW) of the gastrointestinal tract in pullets at 45 days of age.

Treatment	Relative weight			Relative length				
	Digestive tract[a]	Proventriculus	Gizzard	Duodenum	Jejunum	Ileum	Ceca	Small intestine
AMEn[b]								
Low	144.1[a]	6.2[a,b]	36.7[a]	41.3	113.0	94.4	23.5	248.7
Medium	138.9[a]	6.3[a]	35.5[a]	40.6	110.8	91.5	23.1	242.8
High	129.2[b]	5.8[b]	28.9[b]	39.8	108.4	90.0	22.7	238.2
S.E.M.[c]	2.24	0.12	1.08	0.79	2.18	1.71	0.57	4.25
FF								
Mash	146.7	6.3	39.9	41.08	113.5	94.8	24.3	249.3
Pelleted	128.0	5.9	27.4	40.09	108.0	89.1	21.8	237.2
S.E.M.[d]	1.83	0.10	0.88	0.65	1.78	1.39	0.47	3.47
Effect[e]								
AMEn	***	*	***	0.40	0.34	0.20	0.63	0.23
FF	***	*	***	0.29	*	**	***	*

(a–c) Mean values within a column and main effects not sharing a common superscript are different ($P<0.05$).

* $P<0.05$.

** $P<0.01$.

*** $P<0.001$.

[a] Weight of the digestive tract (from the beginning of the proventriculus to cloaca), including digesta content, the liver and the pancreas.

[b] AMEn was 11.44. 12.05 and 12.66 MJ/kg from 1 to 45 d, 11.11, 11.71 and 12.32 MJ/kg from 46 to 85 d and 10.96, 11.55 and 12.13 MJ/kg from 86 to 120 d of age for the low, medium, and high energy diets, respectively.

[c] Standard error of the mean (16 replicates of 2 pullets each).

[d] Standard error of the mean (24 replicates of 2 pullets each).

[e] The interaction between AMEn concentration and feed form was not significant ($P>0.05$).

Table 6
Influence of metabolizable energy content (AMEn) and feed form (FF) of the diet on relative weight (g/kg BW) and length (cm/kg BW) of the gastrointestinal tract and gizzard pH in pullets at 120 days of age.

Treatments	Relative weight			Relative length					Gizzard pH
	Digestive tract[a]	Proventriculus	Gizzard	Duodenum	Jejunum	Ileum	Ceca	Small intestine	
AMEn[b]									
Low	125.5	3.3	23.3[a]	18.3	45.8	43.9	18.5	107.9	3.82
Medium	121.7	3.2	21.1[b]	18.4	44.9	42.2	17.7	105.4	3.84
High	119.0	3.1	20.9[b]	18.8	46.4	43.2	18.4	108.3	3.89
S.E.M.[c]	2.61	0.09	0.53	0.41	0.91	0.92	0.33	1.97	0.100
FF									
Mash	125.1	3.4	22.9	18.6	45.9	43.8	18.5	108.4	3.79
Pellet	119.1	3.1	20.7	18.3	45.4	42.4	17.9	106.1	3.91
S.E.M.[d]	2.13	0.07	0.43	0.44	0.74	0.75	0.27	1.61	0.081
Effect[e]									
AMEn	0.22	0.17	**	0.67	0.50	0.44	0.21	0.54	0.87
FF	0.06	**	***	0.48	0.65	0.18	0.10	0.33	0.33

(a–c) Means within a column and main effects not sharing a common superscript are different ($P<0.05$).
** $P<0.01$.
*** $P<0.001$.
[a] Weight of the digestive tract (from the beginning of the proventriculus to cloaca), included digesta content, the liver and the pancreas.
[b] AMEn was 11.44, 12.05 and 12.66 MJ/kg from 1 to 45 d, 11.11, 11.71 and 12.32 MJ/kg from 46 to 85 d and 10.96, 11.55 and 12.13 MJ/kg from 86 to 120 d of age for the low, medium, and high energy diets, respectively.
[c] Standard error of the mean (16 replicates of 2 pullets each).
[d] Standard error of the mean (24 replicates of 2 pullets each).
[e] The interaction between AMEn concentration and feed form was not significant ($P>0.05$).

affected by the energy content of the diet. At 120 d of age, the only difference observed was for RW of the gizzard that was higher ($P<0.01$) in pullets fed the LOW diet than in those fed the HIG and MED diets (Table 6).

Feeding pellets reduced the RW of the gizzard ($P<0.001$), proventriculus ($P<0.05$) and digestive tract ($P<0.001$) at 45 d of age. Also, the RL of the SI ($P<0.05$), jejunum ($P<0.05$), ileum ($P<0.01$) and ceca ($P<0.001$) was reduced at this age. However, at 120 d of age, the only differences observed were for the RW of gizzard ($P<0.001$) and proventriculus ($P<0.01$) that were heavier for pullets previously fed mash than for those fed pellets. Gizzard pH at 120 d of age was not affected by diet.

4. Discussion

4.1. Productive performance

Body weight gain and FCR of pullets improved as the energy concentration of the diet increased, which agree with data of Summers et al. (1987) with increases in the AMEn of diets of SCWL pullets from 1 to 16 wk of age from 10.44 to 12.45 MJ/kg. Also, Keshavarz and Nakajima (1995) observed that increasing the AMEn concentration of the diet of SCWL pullets from 10.88 to 12.97 MJ/kg from 14 to 18 wk of age reduced ADFI and improved growth performance. Moreover, Keshavarz (1998) reported that an increase in the AMEn concentration of the diet from 11.78 to 12.70 MJ/kg for the last 10 wk of the rearing period, improved performance of SCWL pullets. In contrast, Summers and Leeson (1993) reported that a 10% increase in the AMEn content of the diet of SCWL from 16 to 20 wk of age did not affect BW at 20 wk of age. The authors indicated that in order to be effective in improving BW, the increase in AMEn of the diet should be done earlier in the rearing period. These results agree with the data of the current trial in which an increase in AMEn content of the diet from 10.96 to 12.13 MJ/kg fed to pullets from 12 to 17 wk improved FCR but not BWG.

Leeson et al. (1996) provided diets to broilers containing 11.3–13.8 MJ AMEn/kg and observed no change in growth rate. These authors concluded that the more recent genetic strains of broilers used by the industry possess a good ability to control feed intake based on their desire to normalize energy intake. However, in the current trial, pullets fed the lower energy diets had lower final weights than pullets fed the high energy diets. Probably, differences in the objectives for genetic improvement for broilers and pullets account for the differences detected between broilers and pullets.

In the current research, an increase in the AMEn content of the diet did not affect BW uniformity, which does not conform to data of Keshavarz (1998) who found that uniformity of SCWL pullets at 18 wk of age improved when the AMEn content of the diet fed from hatching to 18 wk of age was increased from 11.78 to 12.70 MJ/kg. Also, Brickett et al. (2007) found that BW uniformity of 35 d old broilers was improved when the AMEn content of the diet was increased from 11.71 to 12.97 MJ/kg.

Pelleting increased ADFI and BWG of pullets from 1 to 45 d of age in agreement with results of Corchero et al. (2008) in broilers from 1 to 42 d of age and consistent with data of Sibbald (1979), who observed that pelleting increased the rate of passage of the digesta in adult roosters. Consequently, feeding pellets should improve feed consumption in poultry. In addition, the application of steam and mechanical pressure to the meal to agglomerate feed particles improves bulk density and feed texture, which in turn might benefit feed intake. In the current experiment, pullets fed pellets from 1 to 45 d of age had higher BWG from 1 to 120 d of age than pullets fed mash, in agreement with data of Frikha et al. (2009) using the same strain of pullets. Consistent with these results, Gous and Morris (2001) found that pullets fed crumbles from 1 to 4 wk and then pellets from 5 to 20 wk of age were 6% heavier than pullets fed mash. Also, Deaton et al. (1988) reported that feeding pellets to pullets from 12 to 20 wk of age increased BWG, but in this research ADFI was not affected.

It has been reported that feeding pellets consistently improved FCR in broilers (Quentin et al., 2004; Amerah et al., 2007) and in pullets (Gous and Morris, 2001). Hamilton and Proudfoot (1995) indicated that the improvement in FCR with pelleting was a consequence of the increase in nutrient digestibility. In fact, Wahlström et al. (1999) observed that the digestibility of starch and fat in laying hens increased when the feed was crumbled. Pelleting might disrupt the structure of the cells' walls and starch granules of maize and other ingredients, releasing part of the intracellular fat contained in the oil bodies and facilitating the access of endogenous enzymes to nutrients. Consequently, energy utilization and FCR will be improved (Gracia et al., 2009). However, in the current experiment, feeding pellets did not affect FCR which agrees with data of Bolton (1960), Plavnik et al. (1997), and Brickett et al. (2007), that failed to find any significant advantage of feeding pellets on FCR or nutrient digestibility in broilers. Moreover, Svihus and Hetland (2001) found that pelleting increased ADFI but reduced nutrient digestibility, and García et al. (2008) observed that heat processing of the cereal did not affect organic matter digestibility or N retention in broilers diets. Feed wastage is higher with mash than with pelleted diets and non-recorded feed wastage might help to explain the higher ADFI and poorer FCR observed when mash diets are used. Our data support the hypothesis that pelleting of the diet has little effect on nutrient digestibility, and that most of the improvement in feed efficiency observed with pelleting by some authors is probably due to a reduction in feed wastage. In this respect, Medel et al. (2004) and Corchero et al. (2008) found that pelleting reduced feed wastage by 6.6% in piglets and by 8.5% in broilers from 1 to 14 d of age, respectively. In fact, Medel et al. (2004) indicated that the improvement in FCR observed with pellet feeding was due primarily to a reduction in feed wastage.

4.2. Gastrointestinal tract development

An increase in the AMEn concentration of the diet reduced the RW of the gizzard at 45 and 120 d of age without affecting the RL of the GIT. High energy diets contain less fibre and more fat than low energy diets. Summers and Leeson (1986) and González-Alvarado et al. (2007, 2008) found that a decrease in the fibre content of the diet reduced gizzard weight in broilers and in laying hens results that are consistent with the findings of the current research.

At 45 d of age, feeding pellets decreased the RW and the RL of all the segments of the GIT except the RL of the duodenum. However, at 120 d of age the only differences observed were for the RW of gizzard and proventriculus, that were higher for the mash than for the pelleted diets. The results agree with data of Frikha et al. (2009) who reported that feeding pellets from 1 to 45 d of age reduced the RW of the gizzard and proventriculus and also the RL of the jejunum and ileum in Hy-Line Brown pullets. In broilers, feeding crumbles or pellets consistently reduced the RW of the gizzard (Choi et al., 1986; Nir et al., 1994). Similar results have been reported by Scott and McCann (2008) in laying hens fed pellets from 30 to 36 wk of age. Moreover, Nir et al. (1995) found that pelleting reduced by 15% the RL of the jejunum and ileum of broilers, and Amerah et al. (2007) reported that the improvement in broiler performance observed with pelleting was associated with a decrease in the RL of the GIT. Gizzard pH at 120 d of age was not affected by diet, a finding that disagrees with data of Huang et al. (2006) and Corchero et al. (2008) that reported higher gizzard pH in broilers fed pellets than in broilers fed mash. However, in the current research pullets were fed a mash diet from 45 to 120 d of age which might have reduced the negative effects of pelleting on gizzard pH.

5. Conclusions

An increase in the energy content of the diet of Hy-Line Brown pullets improved pullet performance at all ages but had no effects on BW uniformity. Feeding pellets from 1 to 45 d of age improved BWG and ADFI at this age but FCR was not affected. The beneficial effects of feeding pellets from 1 to 45 d of age on BWG were maintained at 120 d of age. Increasing the AMEn concentration or pelleting of the diet fed from 1 to 45 d of age, reduced the RW of the gizzard at 120 d of age, a finding that has to be taken into account in pullet rearing because a poor development of the gizzard might affect productive performance at the onset of the egg-laying period.

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